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Ultrashort Light Pulses in Optical Augmentation

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JAMES N. BRADFORD AND JOHN F. GIULIANI

Optical Physics Branch
Optical Sciences Division

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NAVAL RESEARCH LABORATORY
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CONTENTS

ABSTRACT

The development of ultrashort light pulses has led to the examination of these pulses for specialized applications. One particular application would be in the area of optical augmentation, where one seeks to determine the function of an enemy optical system by remote probes. The major parameters needed to reconstruct such a system are the focal length, number of optical elements in the system, element spacing, index of refraction, surface curvature, field of view, and f-number. The f-number is a good clue to a system's function. This number can be found in principle by using radar-like, timed, subnanosecond light pulses to measure focal length, and also using multiple or movable detectors to map the distribution of the reflected light intensity, which leads to a measure of the target aperture.

It has been found, both theoretically and experimentally, that the focal length of a system can be measured using present technology out to a range of nearly 1 km with a quasi-cw high-repetition-rate laser, and to perhaps 30 km with a high-intensity isolated-pulse laser. This excludes, however, systems utilizing reflecting elements or telephoto lenses. Also, aperture measurement is impractical due to the great extent of the spatial intensity distribution in the detector plane. Consequently, the f-number cannot be readily determined.

In conclusion, we believe that this approach will not be profitable because of the limited information it provides and because of the broad classes of systems from which it is excluded.

PROBLEM STATUS

This is a final report on a problem which is now closed.

AUTHORIZATION

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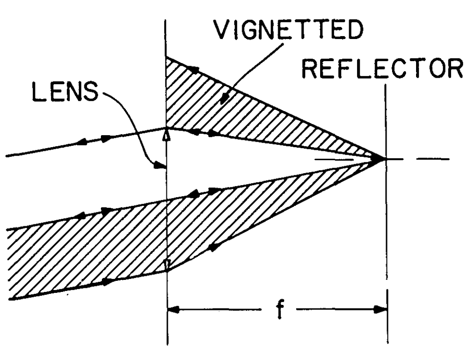
ULTRASHORT LIGHT PULSES IN OPTICAL AUGMENTATION

INTRODUCTION

The goal of optical augmentation is to provide an observer with important and useful information about the function of a remote enemy optical system. In advancing toward that goal, it is natural to seek measures of the focal length, number of elements in the system, element spacing, index of refraction, surface curvature, field of view, and f-number—all major parameters needed to reconstruct the focusing system in a rough way.

Recently, Eckardt and Rabin (1) performed a preliminary investigation of a radar-like approach that would give the first three of the above measures. Projecting a train of about one hundred subpicosecond pulses from a mode-locked neodymium-glass laser, they timed the reflections from a refracting optical system. In this train, the pulses were separated by 9 ns. Returning at different times, reflections from successive optical surfaces formed a pulse sequence, which could be displayed by an oscilloscope or a streak camera. The time between pulses was a measure of the spatial separation of the reflecting surfaces.

Examining reflections from plane surfaces, they found that, when the return pulses were of comparable intensity, they could resolve a reflector spacing of 7.5 cm with a photodiode and an oscilloscope, or 1.5 cm with a commercial image-converter streak camera. When they looked at returns from a simple military telescope, however, it became clear that the major problem was not time resolution but dynamic range, for the objective reflection was swamped by a retroreflection (Fig. 1) from the reticle in the objective focal plane. Their calculations for a simple telescope, comprising an objective, a reticle, and an eyepiece, showed that, at a range of 10 km, the relative intensities of the reflected signals would spread over eight orders of magnitude. No existing detector can manage that spread.



(●) Fig. 1—Illustration of retroreflection. When a simple military telescope was investigated at a distance with a train of subpicosecond laser pulses, the retroflected signal from a reticle in the objecting focal plane completely swamped the signal reflected from the objective lens.

Without considering further the realities of the detector problem, Eckardt and Rabin found that long ranges (up to 100 km) would be readily achieved with the pulsed laser system and a series of amplifier stages. In principle, pulse energies from 1 mJ to 10 J can be projected, with amplifier gains of from 1 to 10^4. For short ranges, of course, attenuation of the oscillator output to well below 1 mJ would be appropriate.

In their report, Eckardt and Rabin did not attempt to evaluate the difficulty of obtaining data in their approach. Nor did they discuss the problems associated with field deployment and operation of a massive, bulky, and very complicated laser system. Furthermore, they did not consider the remaining three interesting parameters of an optical system: surface curvature, field of view, and f-number.

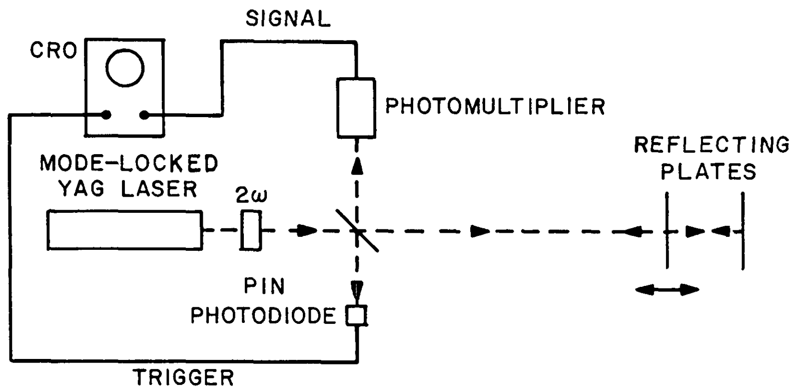
The most vital fact to be learned about a military optical device is its function. Of the parameters we have listed, the one giving by far the best clue to function is f-number. As the work of Eckardt and Rabin has suggested, a system that detects and times the reflections of a projected picosecond light pulse from a refracting optical system can give a reasonable measure of focal length, if the problem of dynamic range in the detector can be resolved. Target aperture, the remaining factor in the f-number, will emerge, in principle, from a measurement of the intensity distribution in the object-lens reflection transverse to the projector-target axis. One way the operator might be able to make that measurement work is by the projection of a Gaussian beam whose diameter and wavefront curvature he can vary and control (2). It should be reasonably easy to build a variable-focus projector to do that. The Gaussian is desirable because it is the only distribution that is not changed by diffraction or focusing. The idea is to observe when the distribution becomes nonGaussian as the projected beam changes from underfilling the target aperture to overfilling. Since the projected beam is controlled, the diameter of the beam at the target will be known when the character of the distribution changes. With these two measurements of focal length and aperture, the f-number will be determined.

A major disadvantage of Eckardt and Rabin's scheme is that, although it is powerful, the source laser emits a pulse or a brief burst of pulses only three time per minute. At that rate, the effects of changes in beam parameters will be difficult and tedious to record. In fact, it will be difficult even to locate the target. In contrast, a high-repetition-rate continuously running laser would encourage a continuous real-time oscilloscope display with rapid data collection.

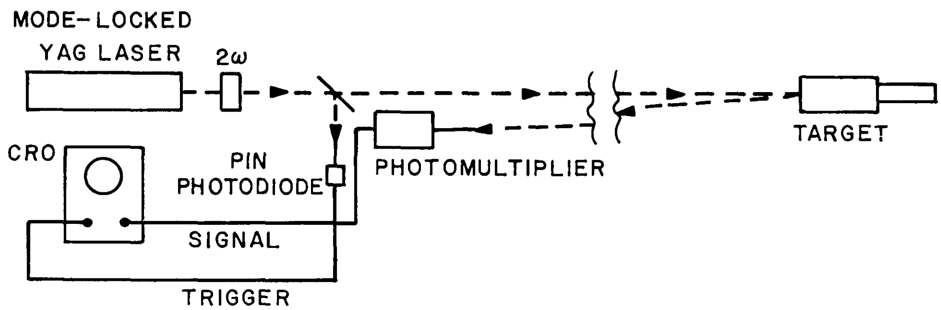
Motivated by the need to assess finally the technical feasibility of useful pulse-time optical augmentation measurements, we have mounted a simple experimental program exploiting the quasi-cw character of a mode-locked cw YAG laser. In the experiments, we have tried to make those laboratory measurements that relate to focal length and that can be validly extrapolated to interesting and meaningful field ranges. We have sought to show definitively, as well, whether aperture can also be derived from a pulse technique of this kind. In all the measurements, we have had the advantage of a real-time visual signal display.

THE EXPERIMENT

The experimental apparatus (Fig. 2) consisted of a source of optical pulses, a target optical system, a photodetector, and a display oscilloscope. For the initial time-resolution measurements, the detector was optically on the source-target axis (Fig. 2a). Later, in studies of a real optical device, we deliberately kept the detector off axis (Fig. 2b), both for control of the relative pulse intensities received and for studies of transverse intensity distribution.



(a)



(b)

Fig. 2—Experimental apparatus used to make a definitive assessment of the usefulness of pulse-time optical augmentation measurements. (a) Detector optically on the source-target axis, and (b) detector off the source-target axis.

Pulse Source

(U) A Holobeam Series 250 YAG laser supplied the fundamental optical pulses for our measurements. It was electrooptically mode-locked by means of a barium sodium niobate crystal within the laser cavity and emitted 100-ps pulses at a wavelength of 1.06 μm. The average output power was 3 W and, considering the pulse width and the pulse repetition rate of 100 MHz, the power at the pulse peaks was about 300 W, giving a pulse energy of 3×10^{-8} J. The laser oscillated in the TEM_{00} mode.

(U) To match the available detectors, we generated a wavelength of 530 nm, the second harmonic of the laser frequency. Frequency doubling occurred in a 90-degree barium sodium niobate crystal, which was temperature tuned for phase matching at the fundamental and harmonic frequencies. The doubler was placed only a few centimeters from the output mirror, where the laser beam was still quite small, but we made no further attempt to maximize conversion efficiency. As a result, the green-light pulse energy in the projected beam was only 3×10^{-13} J, and the peak power was 3 mW.

Detection

(U) We chose a high-speed photomultiplier, RCA Type C31024, to detect the reflected signal pulses. This was the best of three fast photomultipliers available to us. Composed of potassium, cesium, and antimony, the 5-cm photocathode showed a responsivity of about 20 mA/W at a wavelength of 530 nm, and essentially zero at 1.06 m. Five gallium phosphide dynodes developed a current gain of 6.6×10^5 with 3000 V applied to the cathode-dynode voltage divider. The anode risetime appeared to be about 1 ns. Of the two photomultipliers that were not used, one was an ITT Type F4034, and the other a Sylvania Model 502 Crossed-Field Detector. Two disadvantages plagued the F4034 relative to the RCA tube. Although its risetime and photocathode responsivity were comparable, its anode dark current was a thousand times greater at the operating voltage, a consequence of the extended red sensitivity of the S20 photocathode. Signals were immersed in a heavy noise background. Added to that was the difficulty of placing the radiant flux on an effective photocathode only 4 mm in diameter. A different kind of trouble marked operation of the Sylvania, although it, too, had a restricted photocathode, only 2.5 mm in diameter. While signals initially looked quite good, a rapid "fatigue" dropped the anode current dramatically (from which it recovered) in a minute or so, a behavior that appears not to be typical. Otherwise, this tube, with rise and fall times of 100 ps (our measurements), is the one to choose for this application.

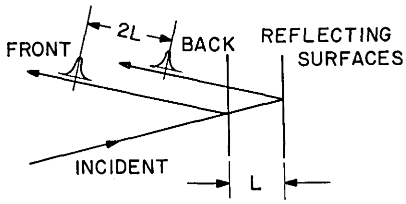
(U) We fed the photomultiplier signals to a Type 1S1 sampling unit in a Tektronix Type 555 oscilloscope, triggered externally by signals from a PIN photodiode monitor. Although the sampling unit risetime was only 0.35 ns, the overall system risetime, established by the photomultiplier, appeared to be 1 ns. Responsivity as large as 0.5 cm/mV, with 50-ohm input impedance, was available in the samping unit.

THEORY AND RESULTS

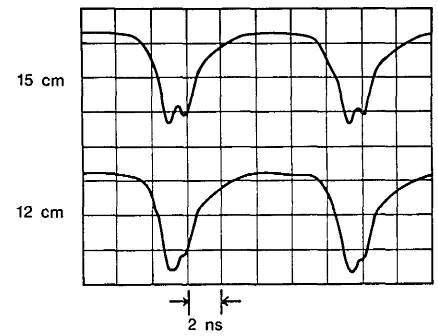
Time Resolution

(U) As an example of pulse timing, consider two reflecting surfaces separated by a distance L (Fig. 3). Each surface will reflect the incident pulse at a different time, and the time separation of the reflected (and eventually detected) pulses will be $\Delta t = 2L/c$, where c is the speed of light. Whether these two pulses will be resolved depends on the response time of the detector. If the full width at half maximum of the pulse emerging from the detector is τ, the smallest reflector spacing that can be resolved will be, approximately, $L_{\text{min}} \approx \tau c/2$. The photomultiplier we have used in these experiments responds with a pulse about 1 ns wide, and we would expect $L_{\text{min}} \approx 15$ cm. Actually, if the pulses are of comparable height, it is possible to resolve 12 cm (Fig. 4) with the arrangement of Fig. 2a. Under those conditions the effective risetime was 0.8 ns rather than the 1 ns we measured directly.

(U) The Sylvania Crossed-Field Detector would permit $L_{\text{min}} \approx 1.5$ cm, the best performance that stock commercial phototubes will allow. It is about the best the YAG laser will allow, as well. It is tempting to try to take advantage of the picosecond speed of



(U) Fig. 3—Illustration of time separation of two reflected pulses from a single pulse incident on two reflecting surfaces

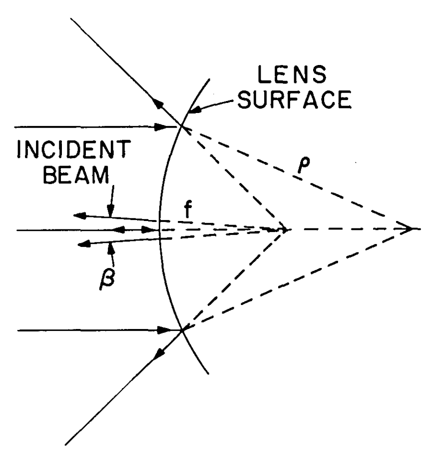


(U) Fig. 4—Oscillograms of pulse reflection from two plates separated by 15 cm (top trace) or 12 cm (bottom trace)

some nonlinear optical processes, such as two-photon fluorescence, to measure very small spatial separations. However, these processes have very small coefficients, and they are dependent on the square, or higher powers, of the light intensity. That means the pulse intensities must be very high, many orders of magnitude greater than the most intense returns.

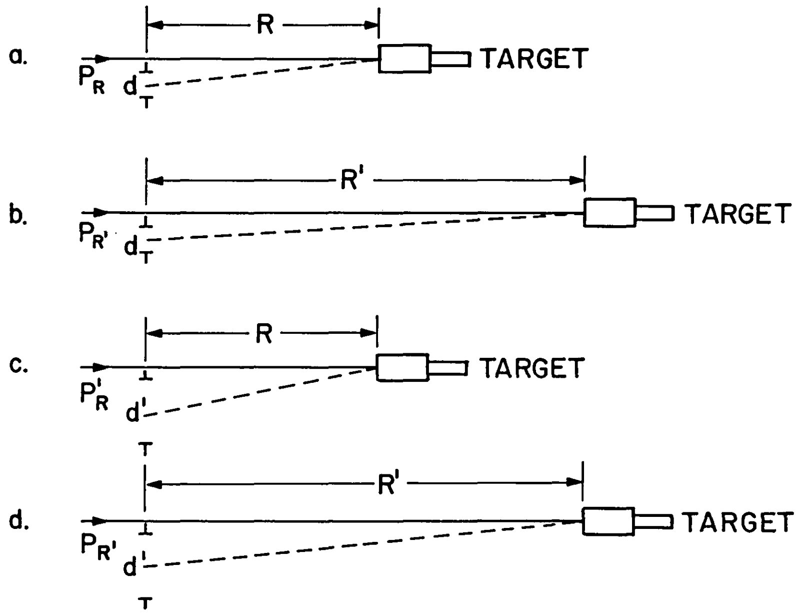
Target Reflection

In measuring the focal length of a real refracting optical system, an even more vital consideration is whether reflections from object lenses can be detected at worthwhile distances, say kilometers. Since the receiver accepts reflected light only within the solid angle it subtends at the reflection focal point of the target objective lens, a very small part of the target aperture is involved. Clearly, the diameter of the target aperture does not matter. Only the power (or energy) density of the light incident normally on the surface, that is, along a surface radius, is important (Fig. 5). We will first develop formulas relating radiant power, range, and receiver aperture (Fig. 6).



(●) Fig. 5—Reflection from a convex spherical lens surface. The angle β is subtended by the receiving aperture.

Assume we have a variable-focus projector and can place the entire projected beam on a fixed area of the target aperture, regardless of range, and let the minimum usable projected power (to give a 2:1 signal-to-noise ratio, say) for range R be P_R. Then the minimum usable power at another range R', is $P_{R'} = P_R(R'/R)^2$. Given a limited power P_R', the range at which it can be just detected usably is $R' = R(P_R'/P_R)^{1/2}$. Because we have assumed that the target is illuminated with the same power distribution at all ranges, the fourth root of power, familiar



(U) Fig. 6—This figure illustrates the definitions of projected power, range, and receiver aperture. The four conditions illustrated are: a. P_R is the least power necessary to produce a usable signal in aperture d at range R; b. $P_{R'}$ is the least power necessary to produce the same signal at range R'; c. P'_R is the smallest projected power for a usable signal in aperture d' at the original range R; d. $P_{R'}$ is the *new* minimum power for the same signal in aperture d' at range R'.

in radar problems, does not apply. These formulas assume a fixed receiving aperture of diameter d. If $P_{R'}$ is limited, the range may be increased by increasing the receiver aperture. Let the aperture increase from d to d' and let P_R be the limiting value of $P_{R'}$. Then the minimum usable power at range R is $P'_R = P_R(d/d')^2$, and $R' = R(P_{R'}/P'_R)^{1/2} = R(d'/d)(P_{R'}/P_R)^{1/2} = R(d'/d)$. In all these formulas, a change in receiver sensitivity may be translated, by the same factor, as a change in projected power.

For the target, we selected a simple visual telescope with a cemented achromatic objective (antireflection coated) and a Ramsden eyepiece. There was no focal plane reticle and no true retroreflection, although the plane surface of the eyepiece field lens was near enough the focal plane to produce a return tightly concentrated about the source-target axis. The object lens focal length was about 30 cm, and the radius of the curvature ρ of the front surface was $\rho = 236$ mm. For front surface reflection the focal length f was (1) $f = \rho/2 = 118$ mm (Fig. 5).

Let a light beam with a Gaussian radial intensity profile be incident on the target at range R. Assume that the beam waist (the focus, where the beam is smallest and the wavefront is plane) is w_0 at range R and that $2w_0$ is sufficiently smaller than the diameter of the target aperture that the Gaussian profile is effectively not truncated (2). At the target, the Gaussian intensity distribution is $I = I_0\exp(-2(r/w_0)^2)$. If w_0 is small enough, the angular distribution of the objective reflection will be $I = I_0\exp(-2(\alpha/\alpha_0)^2)$, where α_0 is the angle subtended by w_0 at the reflection focus. In the receiver plane, that transforms to $I^* = I_0^* \exp(-2(r^*/r_0^*)^2)$, where $I_0^* = (I_0 f^2/R^2) \times$ (target reflectance). Then the $1/e^2$ point is at $r^* = r_0^* = w_0 R/f$. As w_0 becomes larger, the simple angle-space transformation eventually will no longer hold, and the spatial distribution will be more complicated.

Although, with $f = 118$ mm and $w_0 = 1/2$ cm the $1/e^2$ points subtend nearly 5 degrees, the simple transformation is still fairly good. However, r_0^*, the critical characteristic of the Gaussian distribution, will be very large for interesting field values of R. For example, if $R = 1$ km, $r_0^* = 43$ m. With such a large dimension, it seems impractical to measure r_0^* and, consequently, the distribution associated with it. Broader distributions, such as may be caused by large w_0's or by reflection from more strongly curved lenses, will make the measurement even more impractical. Our source beam profile seemed broader and flatter than Gaussian, and, for a target range of 15 m, we were unable to detect any reflected intensity variation in the 86-cm transverse space available off axis (three degrees). While such a distribution may transform to one with somewhat narrower structure at greater ranges, it seems unlikely that truly definitive measurements can be made in reasonable transverse distances.

Since aperture measurement by the scheme we have proposed will depend on the detection of perturbations caused by convolution of the Gaussian distribution with a circular aperture, detector noise will limit the lower level at which the disturbances can be seen and, consequently, limit the accuracy of an aperture measurement. It is evident, too, that a signal-to-noise ratio greater than 2:1 is necessary for measurement of even the simplest continuous intensity distribution. Adding to the already huge difficulties, the retroreflection and reflections from intermediate surfaces in the target will distort the objective distribution in the receiver plane.

Our Gaussian-like beam, with $w_0 \approx 1/2$ cm, was centered on the 3.7-cm target aperture at 6 m range. The receiving aperture of $d = 5$ cm was centered 5 cm off the source-target axis. Protected from all but the second harmonic light, the photomultiplier produced an electrical signal of 10 mV (Fig. 7), a level we judged just comfortably usable in the presence of photomultiplier shot noise (signal-to-noise ratio $\approx$ 2:1). Increasing the receiver aperture to $d' = 13$ cm by means of a lens, we moved the target out to range R' to give the same electrical response we obtained at 6 m. Since the projected power $P_{R'}$ for range R' equals the power for the range R, $R' = R(d'/d) = 15$ m. The electrical response at 15 m was, as we had predicted, 10 mV.

The detection limitation appears to be photomultiplier shot noise. At our operating level the pulses were noisy but cleanly resolved. Much lower signal levels produce noise bursts without clear pulse outlines. At the expense of a rapid display, such weak and noisy signals could be smoothed to produce cleaner pulses.

By placing the detector close to the axis, we were able to observe both the objective reflection and the near retroreflection from the telescope eyepiece (Fig. 7). The clearly separated oscilloscope pulses give a rough measure of the objective focal length. A low-reflectance beam splitter on axis and a mirror at the edge of the photomultiplier aperture would also allow true retroreflections to be observed.

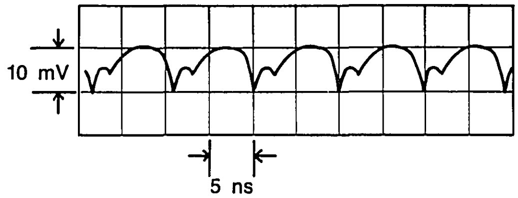


Fig. 7—On this tracing of a target oscillogram, the first spike in each pulse pair arises from the telescope objective lens, and the second arises from the near retroreflection. About 5 mV of noise at the peak has been averaged in this tracing.

(U) With care, the second harmonic power can be increased by a factor of about 3×10^4, to 100 W peak. Assuming again that the projected beam is focused so that it falls on the same area of the target as before, regardless of range, the maximum range at which measurements could have been made on our target with the 13-cm receiving aperture is $R_{max} = R' \times (\text{power increase})^{1/2} = 15 \times 1.73 \times 10^2$ m = 2.6 km. If the receiver aperture were increased to a reasonable 50 cm, the range would be pushed out four times farther to 10 km (Table 1). We have dealt so far with green light. Switching to the fundamental laser wavelength of 1.06 μm, we can gain a factor of ten in peak power. If we assume that, by cooling, we can obtain performance in an infrared photomultiplier degraded by no more than ten times our present tube, the gain factor becomes unity and there is no advantage. For 1.06 μm, such a tube as that is likely to be the best we can expect in the next few years.

(U) Table 1
Maximum Ranges Attainable for Various Receiving Apertures *d*

d		R_{max} (focused) (km)	R_{max} (unfocused) (km)
cm	in.		
5	2	1	0.07
13	5	2.6	0.175
50	20	10	0.7

So far, our measurements and calculations have been highly idealized. While it is quite reasonable to place a 1-cm Gaussian beam waist at almost any range (2) (100 km, for example), it is unreasonable to center it on a target aperture that does not subtend an angle much greater than (~10 times) the resolution of the aiming system. If we agree that the best pointing accuracy we can achieve without excessive complication is 0.1 mrad (1 m at a distance of 10 km), no target smaller than 1 m can qualify at ranges beyond

1 km. For this reason, we must abandon the focusing scheme and fix a beam divergence in which the $1/e^2$ points subtend at least twice the best pointing accuracy, or 0.2 mrad.

Returning to the original 1-cm-diam distribution, we must now evaluate the power density I_0 at the center and compare it with the divergent beam. That means we have to integrate the Gaussian distribution over the entire transverse plane at the target. For the total power, then, we obtain

$$P_{\text{total}} = I_0 \int_0^\infty \int_0^{2\pi} \exp\left(-2 \frac{r}{r_0}\right)^2 r d\theta\, dr$$

$$= \frac{1}{2} \pi r_0^2 I_0$$

where $rd\theta\, dr$ is the element of area in polar coordinates with the origin at the center of the distribution. From this, we find that $I_0 = 2P_{\text{total}}/\pi r_0^2$. Letting $P_{\text{total}} = 100$ W, an attainable green light power, and recalling that $r_0 = 1/2$ cm, we get for the central power density $I_0 = 270$ W/cm^2. In the earlier calculations, this value would be the power density on the center of every target at all ranges. However, allowing $2r_0$ (the $1/e^2$ points) to subtend an angle $2\alpha = 0.2$ mrad and using the formula for I_0, we find the maximum range to be $R_{\max} = R' = R(I_0'/I_0)^{1/2} = R(r_0/r_0') = (Rr_0/\alpha)^{1/2} = 0.7$ km (Table 1). That contrasts sharply with the value $R_{\max} = R = 10$ km that we obtained ideally with the focused beam.

Quite aside from beam aiming difficulties, atmospheric turbulence will spread the beam and introduce time fluctuations in the intensity distribution much of the time. Both effects will tend to reduce the maximum range.

Target Orientation

In the measurements described earlier, the target telescope was pointed at the light source, and the source-target axis coincided with the optic axis of the target. As a result, the center of the light distribution lay on the normal to the front surface of the objective. The reflection was symmetrical about the axis. The near-retroreflection, too, was symmetrical, so the detector azimuth was immaterial with respect to either. The subsequent calculations assumed the same target orientation throughout.

To measure focal length, we must detect both the front-surface and the retro reflection. If the target is not pointed at the light source, but in some other direction, one or both reflections may be lost. The target pointing must meet two requirements. First, the source-target axis must lie along a radius of the objective surface. Otherwise no light can be reflected back to the vicinity of the projector and the first pulse reflection will be lost. Second, the source-target axis must fall within a "field of view" defined by the projection of the target aperture on its focal plane. Outside that "field of view" the retroreflection will be totally vignetted. Other reflections may be detected when the two requirements are not met, and they may lead to confusion or erroneous results.

DISCUSSION

The target in these measurements was a simple and straightforward telescope. The curvature of its objective would be somewhere near average among military optical devices. Measurements on it were easily and uncomplicated by such elements as filters and folding and erecting prisms found in most military telescopes. However, it is unlikely that *some* additional elements will be detrimental to the measurement of focal length, and indeed, a faster detector might locate all the separate components. Yet, if components are too closely spaced, measurement may not be possible since the pulses may not be resolved.

While our experimental target may yield good measurements at ranges approaching 1 km, lenses with greater curvature will enforce shorter ranges, and those with less curvature allow greater ranges. In no instance is the target aperture important. Of the two reflections we are interested in, the aperture influences only the retroreflection, the reflection that overwhelms all others as long as the orientation criteria we discussed earlier are met.

(U) Although we have dealt with the quasi-cw Nd:YAG laser in our work, some other laser systems may compete for this application. Of the mode-locked lasers that have been demonstrated, we have listed the major ones in Table 2. Sticking to the quasi-cw type, the frequency-doubled YAG appears to be the best, offering about one and a half times greater range than the best ion laser wavelength. For the ion laser, time resolution is poorer by a factor of two. As we pointed out earlier, the fundamental wavelength of YAG gives no advantage for the foreseeable future because the detectors are poor, although the longer wavelength may be valuable for other reasons. Again, wavelength may be the only redeeming feature for the CO_2 laser, because both the time resolution and the detector D*† are relatively poor. Among the pulsed systems, the Nd:Glass laser and the dye laser compete strongly, the glass because of its greater pulse energy and the dye because of its tunability, compactness, and relative ease of operation. In the same manner as the Nd:Glass, the dye laser and the pulsed YAG suffer from low repetition rates.

(U) None of the laser systems of Table 2 is simple and entirely easy to operate. None is small or portable enough for a man to carry into the field in his hand or on his back. The ion lasers might be run in a small van, with an auxilliary generator to supply their considerable electric power demand, or in an airplane. With its much greater power requirement and the need for flowing water as a coolant, the quasi-cw YAG laser poses a far more difficult field and air deployment problem. The pulsed systems have even greater bulk, along with substantial coolant and electrical demands, and they will be carried afield only with difficulty. Operation of any of these systems is tricky, and the Nd:Glass laser is especially so.

†The detector D* (read D-star) is defined by the relation $D^* = \sqrt{A\Delta f}/\mathrm{NEP}$ where A is the detector area, Δf is the detector frequency bandwidth, and NEP is the noise equivalent power of the detector.

(U) Table 2
Major Mode-Locked Lasers

Wavelength (μm)	Energy (mJ)	Pulse Width (ps)	Power (W)	Half Width* τ (ns)	Laser*
10.6	0.1	500	2×10^5	1.0	CO_2
1.06	$1\text{-}10^4$	1	$10^9\text{-}10^{13}$	0.005	Nd:Glass (pulsed)
1.06	$1\text{-}10^4$	1	$10^9\text{-}10^{13}$	0.1	Nd:Glass (pulsed)
1.06	10	250	4×10^7	0.25	Nd:YAG (pulsed)
(0.53)	1	170	4×10^6	0.17	Nd:YAG (pulsed)
1.06	10^{-7}	100	10^3	0.1	Nd:YAG
(0.53)	10^{-8}	70	10^2	0.1	Nd:YAG
Yellow-red (tunable)	0.5 0.5	6 6	10^8 10^8	0.006 0.1	Dye (pulsed)
0.6471	10^{-9}	180	5	0.18	Krypton ion
0.5145	2×10^{-9}	180	11	0.18	Argon ion
0.4880	2×10^{-9}	170	11	0.17	Argon ion

*The lasers not marked (pulsed) are quasi-cw. The parameter τ is the half width of the detector response, and all its values, except the first ones for Nd:Glass and the dye, refer to the best detector and an electronic display, such as an oscilloscope. The 0.005- and 0.006-ns values are possible with the fastest streak camera obtainable (Ref. 3).

What may be far more important is that many of the most interesting optical systems are at least partially reflecting and that, among the refracting systems, many are of the telephoto type, with the principal points far removed from the front surface. The kind of measurement we have described cannot reveal the focal lengths of systems in those two classes.

CONCLUSIONS

It is clear that a radar-like light-pulse system can detect remote optical devices by means of retroreflections. However, a cw system may do a better job. A pulse system can also provide some information about the number and spacing of elements in a device, but the information may not be complete. While the pulse method can give focal lengths of some refracting systems, it is of no such use against reflecting systems or telephoto-type refractors. For the most practical source (a quasi-cw laser) the maximum range for observation of reflections other than the retro is severely limited. Although in principle it is possible, in practice it is impossible to measure the aperture of a refractor with a pulse system. That means it is impractical to obtain the most important single parameter, the f-number, of an optical system for the identification of its function. All of the laser systems that might serve as light sources in a pulse system will be difficult to deploy and operate in the field.

(U) We believe this approach to the optical augmentation problem will be unprofitable because of its field operational difficulties, because of the limited information it can provide, and because of the broad and important classes of systems from which it would be excluded.

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13. ABSTRACT

The development of ultrashort light pulses has led to the examination of these pulses for specialized applications. One particular application would be in the area of optical augmentation, where one seeks to determine the function of an enemy opitcal system by remote probes. The major parameters needed to reconstruct such a system are the focal length, number of optical-elements in the system, element spacing, index of refraction, surface curvature, field of view, and f-number. The f-number is a good clue to a system's function. This number can be found in principle by using radar-like, timed, subnanosecond light pulses to measure focal length, and also using multiple or movable detectors to map the distribution of the reflected light intensity, which leads to a measure of the target aperture.

It has been found, both theoretically and experimentally, that the focal length of a system can be measured using present technology out to a range of nearly 1 km with a quasi-cw high-repetition-rate laser, and to perhaps 30 km with a high-intensity isolated-pulse laser. This excludes, however, systems utilizing reflecting elements or telephoto lenses. Also, aperture measurement is impractical due to the great extent of the spatial intensity distribution in the detector plane. Consequently, the f-number cannot be readily determined.

In conclusion, we believe that this approach will not be profitable because of the limited information it provides and because of the broad classes of systems from which it is excluded.

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